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Nutrient Management under Organic Production System in Hill/Mountain Regions

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Abstract

Agriculture, by its nature, depletes essential nutrients from the soil. If soils are to remain productive, nutrients must be replaced by chemical fertilizers, organic fertilizers, farming practices or a combination. The chemo-centric technological advancement during green revolution period boosted the production potential and provided food security in plains. However, over a period of time, this production system has started exhibiting its limited carrying capacity as reflected by production plateau. The success of industrial agriculture in recent decades has masked significant externalities, affecting natural resources, human health, and agriculture itself. Further, increasing consciousness about conservation of environment and health hazards associated with agrochemicals, and consumers' preference to safe and hazard-free food have shifted interests in organic agriculture. Contrary to this, the farmers of hills/mountains have not tasted the fruit of green revolution and ignored chemical inputs, though they are also facing the major challenge of non-availability of organic inputs, especially, nutrient sources to be used in organic production system. The farmers must be aware about how they can efficiently manage the nutrition under organic production system. This article will provide an insight to the farmers on the availability and usefulness of supplementary nutrient sources to enrich the soil for better crops under organic production system in remote mountain regions.

Keywords

Hill/mountain regions; Organic production system; Nutrient management; Soil health

Introduction

Hills and mountains are home to one tenth of the world's population and cover one fifth of the world's land mass. Hill/mountain agriculture faces a number of constraints including inaccessibility, shorter and erratic agricultural seasons, ecological fragility, limited infrastructure, and distant markets. These regions are susceptible to

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accelerated soil erosion, landslides and rapid loss of habitat and genetic diversity. Organic production system is often, by default, non-certified and based mainly on inputs available on the farm. The major challenge in large scale organic agriculture in hill/mountain agroecosystem is the non-availability of huge quantity of organic inputs, especially, nutrient sources (Sanjay-Swami, 2020). In the plains, the chemo-centric technological advancement during green revolution period boosted the production potential and provided food security. But, over a period of time, this production system has started exhibiting its limited carrying capacity as reflected by production plateau in green revolution belt (Sanjay-Swami, 2017a). The success of industrial agriculture and the green revolution in recent decades has often masked significant externalities and decline in agrobiodiversity, affecting natural resources and human health. Further, increasing consciousness about conservation of environment as well as health hazards associated with agrochemicals, and consumers' preference to safe and hazard-free food have shifted farmers' interests in alternate forms of agriculture.

Organic agriculture is one among the broad spectrum of production systems that are supportive of the environment. It has come to be the viable alternative to address the issues thrown as the after-effects of chemo-centric agriculture practiced since 1960. Organic agriculture, without doubt, is one of the fastest growing sectors of agriculture production (Ramesh *et al.,* 2005; Brenes-Muñoz *et al.*, 2016; Das *et al.,* 2020; Gamage *et al.*, 2023). It is a method of farming system, which is primarily aimed at cultivating the land and raising crops in such a way as to keep the soil alive and in good health by use of organic wastes (crop, animal and farm wastes, aquatic wastes) and other biological materials along with beneficial microbes (biofertilizers) (Prasad and Gill, 2009).

A team of the United States Department of Agriculture (USDA) studying organic farming defined, "organic farming is a system which avoids or largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives, etc.) and, to the maximum extent feasible, rely upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection." FAO also suggested that "Organic agriculture is a unique production management system which promotes and enhances agroecosystem's health, including biodiversity, biological cycles and soil biological activity, and this is accomplished by using on-farm agronomic, biological and mechanical methods in exclusion of all synthetic off-farm inputs." In September 2005 in Adelaide, Australia, the General Assembly of IFOAM Organics International passed a motion to establish a succinct definition of organic agriculture. After almost three years of work by a designated task force, a definition reflecting the four principles of organic agriculture in a succinct way was adopted in Vignola, Italy. It is as follows:

> "Organic Agriculture is a production system that sustains the health of soils, ecosystems and people**.** It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."[1]

[1] https://www.ifoam.bio/en/organic-landmarks/definition-organic-agriculture

The concept of organic farming builds on the idea of efficient use of locally available resources as well as the usage of adapted technologies, e.g., soil fertility management, closing of nutrient cycles as far as possible, control of pests and diseases through management and natural antagonists (Sanjay-Swami, 2017b). There may be different management approaches for organic cultivation under different climates, locations and cropping systems. Unlike western developed countries where specialized farming is common, farms in India, especially in hills/mountains, are mostly diversified in terms of crops grown, species and breeds of livestock raised. On-farm diversity is considered good for the organic farming. The North East Region (NER) of India, which is mostly hilly region except Assam, is a hub of organic cultivation by virtue of its soil being organic by default (Sanjay-Swami, 2017a). Approximately 1.8 million ha of land in NER can be classified as "organic by default". In the hills, even today, agriculture remains predominately in the form of shifting cultivation, locally known as '*Jhum*' (Sanjay-Swami, 2018a). This practice has an in-built mechanism of sustenance, conservation and renewable system of resource management (MBDA, 2015). Most of the hill farmers of this region are generally small and marginal in nature and cannot afford to buy the adequate amounts of fertilizers and chemicals necessary for the crop production (Deka and Sanjay-Swami, 2022). Therefore, the NER with its unique characteristics and agricultural practices can be explored as potential area for the introduction of organic farming.

Soil Health Management

Deteriorating soil health is often quoted by the hill farmers as a major reason for adopting organic nutrient supply system, but they are not sure whether all the nutrients in the required quantities can be made available by the organic materials. Knowledge about the availability and usefulness of supplementary nutrient sources to enrich the soil plays a vital role in successful adoption of organic farming in hill/mountain regions. The present article will provide an insight to the hill/mountain farmers on the availability and usefulness of supplementary nutrient sources to enrich the soil for better crops under organic production system.

The major components of soil health management under organic production system are crop rotation, maintenance and enhancement of soil fertility through biological nitrogen fixation, addition of organic manure and use of soil microorganisms, crop residues, biogas slurry, waste, bio-formulations, etc. (Sanjay-Swami, 2017a). Vermiculture has become a major component in biological farming, which is found to be effective in enhancing the soil fertility and producing large numbers of horticultural crops in a sustainable manner (Sanjay-Swami, 2017c).

Various options for nutrient management/soil health management under organic production system are discussed below:

1. Crop rotation

It is a systematic arrangement for the growing different crops in a more or less regular sequence on the same land covering a period of two years or more. The selection of optimal crop rotation is important for successful sustainable agriculture in hills/mountains. Crop rotation is very important for soil fertility management, and weed,

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insect and disease control. Legumes are essential in any rotation and should cover 30 to 50 percent of the land. A mixed cropping, pasture and livestock system is desirable or even essential for the success of sustainable agriculture in hill/mountains.

2. Crop residue

In India, there is a great potential for utilization of crop residues/straw of some of the major cereals and pulses. About 50% of the crop residues are utilized as animal feed, the rest could be utilized for recycling of nutrients. Adequate care is required to use the residues after proper composting with efficient microbial inoculants. While the incorporation of crop residues like wheat and rice straw as such or inoculated with fungal species had beneficial effects on crop yields and important in physico-chemical properties of soil.

3. Organic manure

The organic manure is derived from biological sources like plant, animal and human residues. Organic manure acts in many ways in augmenting crop growth and soil productivity. The direct effect of organic manure relates to the uptake of humic substances or its decomposition products, affecting favourably the growth and yield of plants. Indirectly, it augments the beneficial soil microorganisms and their activities and, thus, increases the availability of major and minor plant nutrients. As livestock is an important component in hill/mountain agriculture, this may serve as a good source of organic manures.

(a) Bulky organic manure: It generally contains lesser amounts of plant nutrients as compared to concentrated organic manure. It includes FYM (farm yard manure), compost and green manure.

- *FYM:* It refers to the well-decomposed mixture of dung, urine, farm litter and left over or used up materials from roughages or fodder feed to the cattle. The waste material of cattle shed consisting of dung and urine soaked in the refuse is collected and placed in trenches about 6 m long, 2 m wide and 1 m deep. Each trench is filled up to a height of about 0.5 m above the ground level and plastered over with slurry cow-dung and earth. The material is allowed to decompose undisturbed 3-4 months for anaerobic microorganism for completion of fermentation. FYM becomes ready to apply after 3-4 months. Well-rotted FYM contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O.

- *Compost:* The waste materials such as vegetable refuse, farm litter (e.g., weeds, stubble, hay, sugarcane trash), sewage sludge and animal waste or excreta can be converted into useful compost manure by subjecting these materials to a controlled process of anaerobic decomposition. Compost is used in the same way as FYM and is good for application to all soils and all crops, especially in hill/mountain regions.

- *Green manuring:* It is a practice of ploughing or turning into the soil under-composed green plant tissues for the purpose of improving physical structure as

well as fertility of the soil. From the time immemorial, the turning-in a green crop for improvement of the soil conditions has been a popular farming practice in hill/mountains. Green manuring, wherever feasible, is the principal supplementary means of adding organic matter to the soil. It consists of the quick growing of crop and ploughing it under to incorporate it into the soil. The green manure crop supplies organic matter as well as additional nitrogen, particularly if it is a legume crop, which has the ability to fix nitrogen from the air with the help of its root-nodule bacteria. A leguminous crop producing 25 tons of green matter per hectare will add about 60 to 90 kg of nitrogen when ploughed under. This amount would equal to an application of 3 to 10 tons of FYM on the basis of organic matter and its nitrogen contribution. The green manure crops also exercise a protective action against erosion and leaching. The most commonly used green manuring crops are: Sunhemp (*Crotalaria juncea*), Dhaincha (*Sesbania aculeata*), Cluster bean (*Cyamopsis tetragonoloba*), Senji (*Melilotus parviflora*), Cowpea (*Vigna catjang, Vigna sinensis*), Berseem (*Trifolium alexandrium*).

Plate 1 & 2: Green manure crop and its incorporation in soil.
Photo credit: AAU, Jorhat

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(b) Concentrated organic manure: Concentrated organic manures are those materials that are organic in nature and contain higher percentage of essential plant nutrients such as nitrogen, phosphorous and potash, as compared to bulky organic manures. These concentrated manures are made from raw materials of animal or plant origin. The concentrated organic manures commonly used in hill/mountain farms are oilcakes, blood meal, fishmeal, meat meal and horn and hoof meal.

4. Waste

1. *Industrial waste:* Among the industrial by-products, spent wash from distilleries and molasses and press-mud from sugar industry have good manurial value. It is important to use only well decomposed press-mud at 10 tons/ha. Addition of press-mud improves the soil fertility and enhances the activity of microbes. Coir waste is the by-product from coir industry and can be used as manure after proper decomposition.
2. *Municipal and sewage waste:* It also forms an important component of organic waste. In India, the total municipal refuse is about 12 metric ton per annum, containing about 0.5% N, 0.3% P_2O_5 and 0.3% K_2O. Sewage sludge is available to an extent of 4 million tons per annum containing 3% N, 2% P and 0.3% K. Particularly from industrialized cities, the sewage sludge is contaminated with heavy metals and these pose hazards to plants, animals and human beings. Separation of the toxic waste at the source will minimize the concentration of such elements in the sludge.

5. Biofertilizers

It has been observed that there is decline in crop yield due to continuous application of inorganic fertilizers. Therefore, need is being felt to integrate nutrient supply with organic sources to restore the soil health. Biofertilizer offers an economically attractive and ecologically sound means of reducing external inputs and improving the quality and quantity of internal sources. Biofertilizer is microorganism's culture capable of fixing atmospheric nitrogen or edaphic phosphorus or sulfur or potash when it is inoculated with suitable crops. The main inputs are microorganisms, which are capable of mobilizing nutritive elements from non-usable form to usable form through biological process. These are less expensive, eco-friendly, sustainable and suitable for smallholder farmers in hill/mountain regions. The beneficial microorganisms existing in the soil are of greater significance to horticultural situations; and they are biological nitrogen fixers, phosphate solubilizers and mycorrhizal fungi.

The biofertilizers containing biological nitrogen fixing microorganisms are of utmost important in agriculture in view of the following advantages:

- They help in establishment and growth of crop plants and trees.
- They enhance biomass production and grain yields by 10-20%.
- They are useful in promoting sustainable agriculture.
- They are suitable for organic farming.
- They play an important role in agroforestry and silvi-pastoral systems.

There are two types of N-fixing biofertilizers:

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1. Symbiotic N-fixation: These are *Rhizobium* cultures of various strains, which multiply in roots of suitable legumes and fix nitrogen symbiotically. Almost 50% demand of N in legumes is met by these microorganisms.

- *Rhizobium* is the most widely used biofertilizer, which colonizes the roots of specific legumes to form tumours-like growths called rot nodules. It is these nodules that act as factories of ammonia production. The *Rhizobium*-legume association can fix up to 100-300 kg N/ha in one crop season.

2. Asymbiotic N-fixation: This category includes *Azotobacter, Azospirillium*, blue green algae, *Azolla* and *Mycorrhizae*, fixing atmospheric N in suitable soil medium. They grow on decomposing soil organic matter and produce nitrogen compounds for their own growth and development, besides that they leave behind a significant amount of N in surroundings.

- *Azotobacter*: Application of *Azotobactor* has been found to increase the yields of wheat, rice, maize, pearl millet and sorghum by 0-30%. The beneficial effect of *Azotobactor* biofertilizer on cereals, millets, vegetables, cotton and sugarcane under both irrigated and rainfed field conditions have been substantiated and documented. Apart from nitrogen this organism is also capable of producing antibacterial and anti-fungal compounds, hormones and siderophores.
- *Azospirillium*: It is an important bacterium, which colonizes the root zones and fixes nitrogen in loose association with plants. The crops which response to *Azospirillum* is maize, barley, oats, sorghum, pearl millet and forage crop. *Azospirillum* applications increase gain productivity of cereals by 5-20%, of millets by 30% and of fodder by >50%.
- Blue green algae: The utilization of blue-green algae as biofertilizers for rice is very promising. Recent researches have shown that algae also help to reduce soil alkalinity and this opens up possibilities for bio-reclamation of such inhospitable environments.
- *Azolla*: Azolla is a free-floating water fern that floats in the water and fixes atmospheric nitrogen because of its association with the nitrogen fixing cyanobacterium, *Anabaena* (Sanjay-Swami and Singh, 2020a). The *Azolla-Anabaena* association is a live floating nitrogen factory using energy from photosynthesis to fix atmospheric nitrogen amounting to 100-150 kg N/ha/year from about 40-64 tons of biomass. The average N, P and K content in *Azolla* on dry weight basis are 4.0-7.0, 0.6-0.8 and 2.0-4.0 per cent, respectively. With a doubling of biomass within two days, *Azolla* ranks amongst the fastest-growing plants on our planet and, thus, can provide large biomass (Sanjay-Swami and Singh, 2019).
- *Mycorrhizae:* Mycorrhizae are the symbiotic association of fungi with roots of vascular plants. The main advantage of Mycorrhizae to the host plants lies in the extension of the penetration zone of the root fungus system in the soil, facilitating an increased phosphorous uptake. In many cases, the Mycorrhizae has been shown to markedly improve the growth of plants. In India, the beneficial effects of vascular-arbuscular Mycorrhizae (VAM) have been observed in fruit crops like citrus, papaya and litchi. Recent studies showed the possibility of domesticating Mycorrhizae in agricultural system.

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Plate 3 & 4: *Azolla* harvesting and its application in paddy field
Photo credit: KVK-Jammu, R.S. Pura

6. Vermicompost

Vermicompost is produced as the vermi-cast by earth worms feeding on biological waste material and plant residues. It is a method of making compost with the use of earthworms that generally live in soil, eat biomass and excrete it in digested form. It is generally estimated that 1,800 worms per sq. meter can fed on 80 tons of humus per year. The excreta of earthworms are rich in macro- and micronutrients, vitamins, growth hormones

and immobilized micro-flora. The average nutrient content of vermicompost is much higher than that of FYM. It contains 1.60% N, 5.04% P_2O_5 and 0.80% K_2O with small quantities of micronutrients. Application of vermicompost facilitates easy availability of essential plant nutrients to crops. It has been emerging as an important source in supplementing/substituting chemical fertilizers in agriculture (Sanjay-Swami, 2019a). Besides higher concentration of available nutrients (macro, secondary and micro) than the ordinary FYM, it has also been reported to enhance plants' ability to fight against insect pests and diseases (Sanjay-Swami, 2012a).

Vermicompost also improves soil structure and physical properties of the soil like soil air, soil temperature, soil water retention and soil mechanical impedance (Sanjay-Swami and Bazaya, 2010). Due to absence of toxic enzymes, it is also eco-friendly and it also has beneficial effect on the bio-chemical activities of the soil (Sanjay-Swami and Bazaya, 2011). There is a growing realization in hill/mountain areas that vermicomposting provides the nutrients and growth enhancing hormones necessary for plant growth (Sanjay-Swami, 2019a). The fruits, flowers, vegetables and other plant products grown using vermicompost are reported to have better keeping quality (Sanjay-Swami, 2018b). A growing number of individuals and institutions are taking interest in the production of compost utilizing earthworm activity. Table 1 shows the composition of nutrients in vermicompost vis-à-vis FYM.

Table 1: Nutrient status of vermicompost and farm yard manure*

Nutrient	*Farm Yard Manure*	*Vermicompost*
N (%)	0.40-0.75	1.0-1.6
P_2O_5 (%)	0.17-0.30	0.50-5.04
K_2O (%)	0.20-0.55	0.80-1.50
Ca (%)	0.91	0.44
Mg (%)	0.19	0.15
Fe (mg/kg)	146.5	175.2
Mn (mg/kg)	69.0	96.91
Zn (mg/kg)	14.5	24.43
Cu (mg/kg)	2.8	4.89
C:N ratio	31.28	15.5

* The values may vary depending upon the type of organic waste used. *Source:* Suthar, 2009

Compost pit of any convenient dimension can be dug in the backyard or in hill/mountain farms. The most convenient pit of easily manageable size is 2 m x 1 m x 0.75 m. A tank may be constructed with brick and mortar having proper water outlets, or a plastic crate (600 mm x 300 mm x 300 mm) with holes drilled at the bottom or empty wooden crates (deal wood boxes/apple cases) or well rings made of cement or clay of 750 mm diameter and 300 to 450 mm height can also be used with slight modifications in the thickness of layers used. If nothing is available, then four worn out car-tyres are placed one above the other and composting can be started in it. To make it simpler, it can also be done in a 25-litre bucket. Vermi-bed (vermi= earthworms; bed= bedding) is the actual layer of good moist loamy soil placed at the bottom, about 150 to 200 mm thick above a thin layer (50 mm) of broken bricks and coarse sand. Earthworms are introduced into the loamy soil, which the worms will inhabit as their home. About 100 earthworms (a

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combination of *epigeics* and *anecics*) may be introduced into a compost pit of about 2 m x 1 m x 0.75 m, with a vermin-bed of about 15 to 20 cm thick. The vermi-bed should always be kept moist, but should never be flooded.

Handful lumps of fresh cattle dung are then placed randomly over the vermi-bed. The compost pit is then layered to about 50 mm with dry leaves or preferably chopped hay/straw. For the next 30 days, the pit is kept moist by watering it whenever necessary. The bed should neither be dry nor soggy. The pit may then be covered with an old jute (gunny) bag to discourage birds from picking and eating earthworms. Plastic sheets on the bed are to be avoided as they trap heat. After the first 30 days, as above, wet organic waste of animal and/or plant origin from the farm or kitchen or hostel or hotel that has been pre-digested is spread over it to a thickness of about 50 mm. This can be repeated twice a week. All these organic wastes can be turned over or mixed periodically with a pick axe or a spade. Care should be taken; not to disturb the vermi-bed in which the worms live. Keep adding garbage till the compost pit is nearly full. Continue to keep the pit moist for another 30 to 45 days, turning over the material in the pit with care avoiding injury to the worms. Turning over can be done on every fifth or seventh day with the help of a forked spade. Regular watering should be done to keep the right amount of moisture in the pits. In 60 to 90 days, the compost should be ready as indicated by the presence of earthworm castings (vermi-compost) on the top of the bed. The compost should be turned occasionally to facilitate aeration. If the weather is very dry, it should be dampened periodically. The pile should be moist, not wet and soggy. Vermi-compost can now be harvested from the bin/pit. The material should be placed in a heap in the sun so that most of the worms move down to the cool base of the heap. The compost is then sieved before being packed. The earthworms and the thicker material, which remains on top of the sieve, go back to the bin and the process starts again. Compost works best with a mixture of coarse and fine materials, layered together. The extra worms that are produced can be used as feed for poultry and fish.

8. Vermiwash

Foliar sprays are a part of organic production practices in hill/mountain farms. Worm worked soils have burrows formed by the earthworms. Bacteria richly inhabit these burrows, also called as the drilospheres. Water passing through these passages washes the nutrients from these burrows to the roots and being absorbed by the plants. This principle is applied in the preparation of vermiwash. Vermiwash is very good foliar spray.

Setting up of vermiwash unit:

Vermiwash units can be set up either in barrels or in buckets or even in small earthen pots. The procedure explained here is for setting up of a 250-litre barrel. An empty barrel with one side open is taken. On the other side, a hole is made to accommodate the vertical limb of a 'T' joint tube in a way that about half to one inch of the tube projects into the barrel. To one end of the horizontal limb is attached a tap. The other end is kept closed. This serves as an emergency opening to clean the 'T' joint tube if it gets clogged. The entire unit is set up on a short pedestal made of few bricks to facilitate easy collection of vermiwash (Sanjay-Swami, 2017a).

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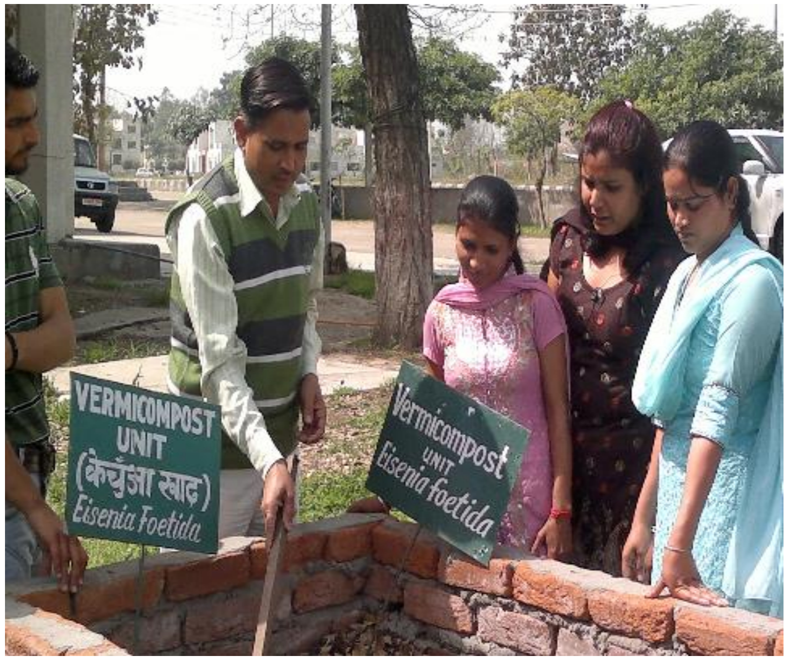

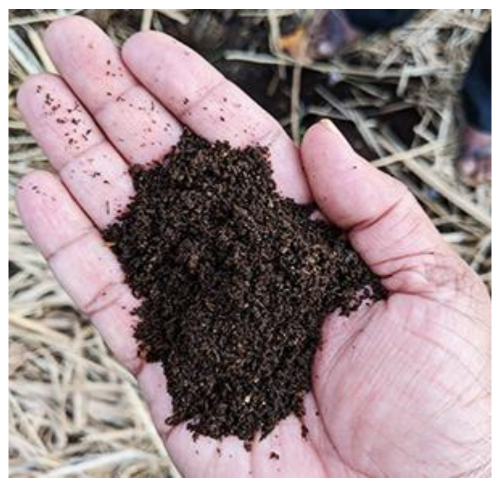

Plate 5, 6 & 7: Vermicomposting unit, earth worms in action and final product.
Photo credit: Sanjay-Swami

Keeping the tap open, a 25 cm layer of broken bricks or pebbles is placed. A 25 cm layer of coarse sand then follows the layer of bricks. Water is then made to flow through these layers to enable the setting up of the basic filter unit. On top of this layer is placed a 30 to 45 cm layer of loamy soil. It is moistened and into this, about 50 numbers each of the surface (*epigeic*) and sub-surface (*anecic*) earthworms are introduced. Cattle dung pats and hay are placed on top of the soil layer and gently moistened. The tap is kept open for the next 15 days. Water is added every day to keep the unit moist. On the 16th day, the tap is closed and on top of the unit a metal container or mud pot perforated at the base as a sprinkler is suspended. 5 litres of water (the volume of water taken in this container is one fiftieth of the size of the main container) is poured into this container and allowed to gradually sprinkle on the barrel overnight. This water percolates through the compost, the burrows of the earthworms and gets collected at the base. The tap of

the unit is opened the next day morning and the vermiwash is collected. The tap is then closed and the suspended pot is refilled with 5 litres of water that evening to be collected again the following morning. Dung pats and hay may be replaced periodically based on a need. The entire set up may be emptied and reset between 10 and 12 months of use. Vermiwash is diluted with water (10%) before spraying. This has been found to be very effective on several plants. If need be, vermiwash may be mixed with cow's urine and diluted (1 litre of vermiwash, 1 litre of cow's urine and 8 litres of water) and sprayed on plants to function as an effecting foliar spray and pesticide (Sanjay-Swami, 2012b).

Table 2: Vermiwash constituents (analysis report)

Parameter	*Value*
pH	7.48 ± 0.03
Electro conductivity (dS/m)	0.25 ± 0.03
Organic Carbon (%)	0.008 ± 0.001
Total Kjeldhal Nitrogen %	0.01±0.005
Available Phosphate %	1.69 ± 0.05
Potassium (mg/kg)	25 ± 2
Sodium (mg/kg)	8 ± 1
Calcium (mg/kg)	3 ± 1
Copper (mg/kg)	0.01 ± 0.001
Ferrous (mg/kg)	0.06 ± 0.001
Magnesium (mg/kg)	158.44 ± 23.42
Manganese (mg/kg)	0.58 ± 0.040
Zinc (mg/kg)	0.02 ± 0.001
Total Heterotrophs (CFU/ml)	1.79 x 103
Nitrosomonas (CFU/ml)	1.01 x 103
Nitrobacter (CFU/ml)	1.12 x 103
Total Fungi (CFU/ml)	1.46 x 103

Source: Sanjay-Swami, 2020

9. Panchagavya

Panchagavya, an organic product, has the potential to play the role of promoting growth and providing immunity in a plant system. Panchagavya consists of nine products *viz.* cow dung, cow urine, milk, curd, jaggery, ghee, banana, tender coconut and water. When suitably mixed and used, these have miraculous effects.

Preparation technique:

Take 7 kg cow dung and 1 kg cow ghee. Mix these two ingredients thoroughly twice in morning and evening hours for 3 days. After 3 days, mix 10 liters cow urine and 10 liters water in it and keep this for 15 days with regular mixing in morning and evening hours. After 15 days, mix 3 liters cow milk, 2 liters cow curd, 3 liters tender coconut water, 3 kg jaggery and 12 well ripened banana in it. The final product i.e., Panchagavya will be ready on completion of 30 days.

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All the above items can be added to a wide mouthed mud pot, concrete tank or plastic can as per the above order. The container should be kept open under shade. The content is to be stirred twice a day both in morning and evening. The Panchagavya stock solution will be ready after 30 days. Care should be taken not to mix buffalo products. The products of local breeds of cow is said to have potency than exotic breeds. It should be kept in the shade and covered with a wire mesh or plastic mosquito net to prevent houseflies from laying eggs and the formation of maggots in the solution. If sugarcane juice is not available add 500 g of jaggery dissolved in 3 litres of water.

Cow dung Cow urine Cow ghee Milk Water

Cow curd Jaggery Tender Coconut Ripened banana

Plate 8: Ingredients of Panchagavya (Photo credit: TNAU, Coimbatore)

Table 3: Physico-chemical and biological properties of Panchagavya

Chemical composition			*Microbial Load*		
pH	:	5.45	*Fungi*	:	38800/ml
EC dSm^2	:	10.22	*Bacteria*	:	1880000/ml
Total N (ppm)	:	229	*Lactobacillus*	:	2260000/ml
Total P (ppm)	:	209	*Totalanaerobes*	:	10000/ml
Total K (ppm)	:	232	*Acidformers*	:	360/ml
Sodium	:	90	*Methanogen*	:	250/ml
Calcium	:	25			
IAA (ppm)	:	8.5			
GA (ppm)	:	3.5			

Source: https://agritech.tnau.ac.in/org_farm/orgfarm_panchakavya.html

10. Bio-char as Nutrient Source

Bio-char is a solid carbonaceous rich material obtained from thermally degrading of crop and agroforestry residues in the presence of little or no oxygen. Almost any form of organic resources can be pyrolyzed into bio-char including various types of forest

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residues (sawdust), agricultural residues like corn cob, corn stalk, wheat straw, rice straw, stalk of pearl millet, cotton, mustard, soybean, and sugar beet tailing and agro-industrial wastes. There are many ways to produce bio-char but all of them involve heating biomass with little or no oxygen to drive off volatile gasses, leaving carbon behind. This simple process is called thermal decomposition usually achieved from pyrolysis. Pyrolysis can be of four types: slow pyrolysis, fast pyrolysis, flash pyrolysis, and gasification. Slow pyrolysis performed under lower temperature (<400-500°C) and with long contact times often results in a high yield of bio-char (35%). Faster pyrolysis or gasification operates at higher temperatures (<800°C) and gives a high yield of combustible gases in comparison to the solid bio-char (12%) (Singh *et al.,* 2023). The most commonly employed method is slow pyrolysis. This process involves direct thermo-chemical decomposition (exothermic reaction) to transform low-density residue matrix into a bio-char at a temperature range of 450-500˚C under low-oxic or anoxic conditions in a closed reactor.

Plate 9 & 10: Bio-char as nutrient source, its application and mixing in soil (Photo credit: O. Srikanth Yadav)

The usefulness of bio-char in the acidic soils of hill/mountain regions increases when it is applied in combination with organic manures like FYM, vermicompost, poultry manure, pig manure, etc. (Chan *et al.*, 2008; Yadav and Sanjay-Swami, 2018). For optimization of bio-char dose to maximize the yield of tomato in acid soil, a field experiment was conducted at School of Natural Resource Management, CPGS-AS, Umiam in mid hills of Meghalaya during *rabi* season of 2017. Tomato cv. Megha tomato-2 was used as test crop with three doses of biochar (B) @ 2, 3 and 4 t/ha, vermicompost (VC) @ 2.5 t/ha and two graded recommended doses of NPK fertilizers (RDF) @ 75 and 100% in sixteen treatment combinations. The results indicated that plant height, number of fruits/plant, fruit size and fruit yield of tomato was higher with the application of biochar @ 4 t/ha with vermicompost @ 2.5 t/ha and 100% RDF and the soil pH showed improvement over control. Hence, the combined application of biochar @ 4 t/ha with vermicompost @ 2.5 t/ha and 100% RDF may be recommended for mid hills farmers of Meghalaya to enhance tomato productivity coupled with managing their acidic soils (Yadav and Sanjay-Swami, 2019; Sanjay-Swami, 2019b).

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Plate 11 & 12: Experimental plots with different treatments and tomato crop at fruiting stage (Photo credit: O. Srikanth Yadav)

Conclusion

Organic farming can be a viable alternative production system for farmers, especially in hill/mountain regions, but there are many challenges too. One key to success is in ensuring the easy and on-time availability of organic inputs in inaccessible remote hill/mountain farms. Recyclable nutrients (N, P, K, S, Zn, Mn, Fe and Cu) from plant and animal waste in large quantity can overcome the synthetic fertilizer usage. Developing local organic manure suppliers in hills/mountains regions by adopting additional entrepreneurs like animal husbandry and collecting biomass from fields and domestic waste may help in this direction. The technology for converting waste into compost needs advancement and potential verification in hill/mountain conditions. Inoculation by improved *Azotobacter* strains can enhance the productivity significantly. Use of PSB (phosphate solubilizing bacteria) helps in increased availability of phosphorous. These steps would help the hill/mountain farmers to adopt organic farming, manage crop nutrient demand, improve the soil health and reduce the cost of cultivation as compared to conventional farming practices.

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Collected the data	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes
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